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RADIOLOGICAL SURVEY OF THE PERIMETER FENCE LINE OF THE FORMER COTTER SITE, HAZELWOOD, MISSOURI (LM002)

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RADIOLOGICAL SURVEY OF THE PERIMETER FENCE LINE OF THE FORMER COTTER SITE, HAZELWOOD, MISSOURI (LM002)

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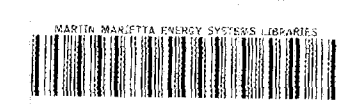

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ABSTRACT

A radiological survey was conducted in 1983 by the Oak Ridge National Laboratory along the perimeter fence line of the former Cotter site at 9200 Latty Avenue, Hazelwood, Missouri. During the 1960s and 1970s, process wastes and residues generated by the production and refining of uranium materials were stored at the site (currently owned by the Jarboe Realty and Investment Company). Subsequent to the removal and transport of the stored wastes along with a portion of the top soil to other locations, it was found that the soil remaining on the site contained radioactive residuals. This report describes the survey of the regions along the fence line that surrounds the property on all sides. Included were gamma scans of the grid blocks on each side of the fence line; sampling of surface soil; sampling of subsurface soil from auger holes; and gamma logging of auger holes. The results of soil sample analyses demonstrate radionuclide soil contamination with maxima for ^{226}Ra, ^{230}Th, and ^{238}U at 1700, 77,000, and 1200 pCi/g, respectively. These concentrations were found in surface soil taken from 0 to 0.15 m. The depth of contamination ranges from the surface to 1.7 m. The maximum contamination measured during this survey was found at an average depth of 0.36 m.

INTRODUCTION

Process wastes and residues associated with the production and refining of uranium materials were generated by the Mallinckrodt Chemical Works, St. Louis, Missouri, during the period 1942 through the later 1950s. According to a Nuclear Regulatory Commission (NRC) report,[1] residues which had been stored at the St. Louis Airport property were moved by the Continental Mining and Milling Company of Chicago, Illinois, to the Latty Avenue Storage Site in Hazelwood, Missouri, in early 1966. The Latty Avenue storage site is located in a low-lying industrialized area in Hazelwood/Berkeley, Missouri, approximately 12 miles northwest of St. Louis. The Commercial Discount Corporation, Chicago, Illinois, purchased the residues in January 1967. Much of the material was dried and shipped to the Cotter Corporation facilities in Canon City, Colorado. These materials included ore residues and uranium-, thorium-, and radium-bearing process wastes. Materials remaining at the Latty Avenue Storage Site were sold to the Cotter Corporation in December 1969. Records indicate that residues remaining on the site at that time included 74,000 tons of Belgian Congo pitchblende raffinate containing 113 tons of uranium, 32,500 tons of Colorado raffinate containing 48 tons of uranium, and 8700 tons of leached barium sulfate containing about 7 tons of uranium. During August through November 1970, Cotter Corporation dried some of the remaining residues and shipped them to a Cotter mill in Canon City, Colorado. An estimated 10,000 tons of Colorado raffinate and 8700 tons of leached barium sulfate remained at the Latty Avenue site in December 1970.

In April 1974, an NRC inspector was informed that the remaining Colorado raffinate had been shipped without drying to Canon City during the prior year (1973) and that the leached barium sulfate had been transported to a landfill area in St. Louis County. Twelve to eighteen inches of top soil were reported to have been stripped from the Latty Avenue site surface and supposedly were removed from the site with the leached barium sulfate. However, analysis of soil samples taken during an NRC investigation of the site in 1976 indicated the presence of uranium- and thorium-bearing residues.[1]

In 1977, a survey was conducted by Oak Ridge National Laboratory (ORNL) to characterize the radiological conditions at the site. It was determined that alpha and beta-gamma contamination levels on surfaces in buildings on the site exceeded NRC guidelines for release of decontaminated property for unrestricted use.[2] Numerous areas having gamma exposure rates of 300–500 μR/h were clearly above criteria recommended by the International Commission on Radiological Protection (ICRP).[3] It was estimated that the top three inches of soil on much of the area contained an average of 140 pCi/g of ^{226}Ra and probably higher average concentrations of ^{238}U, ^{230}Th, and ^{227}Ac.

At the request of the U.S. Department of Energy (DOE), a preliminary survey of properties adjacent to and in the vicinity of 9200 Latty Avenue was made in September 1983 to determine if contamination was present on any vicinity properties and to evaluate the scope of work required to perform radiological assessment surveys on these properties.[4] Elevated gamma radiation levels were observed on all properties adjacent to 9200 Latty Avenue, especially on those properties to the north, east, and south.

In accordance with the results of the preliminary evaluation, a radiological survey of the perimeter fence line surrounding the former Cotter site at 9200 Latty Avenue, Hazelwood, Missouri, was performed by ORNL during the period January through April, 1984. This private property is currently owned by the Jarboe Realty and Investment Company. This report describes the results of that survey limited to the regions immediately adjacent to each side of the fence line that surrounds the property on all sides. At that time, consent was denied for further surveying inside the property boundaries. As a result of discussions with the owner subsequent to the survey of the fence line, DOE obtained access approval and a radiological survey of the remainder of the property has been scheduled. A diagram of the approximate property boundaries and the master grid network established for measurements on and around the site is shown in Fig. 1. The results of radiological surveys of Latty Avenue in the vicinity of the former Cotter site and of nearby properties are provided in separate reports.[5,6]

SURVEY METHODS

The radiological survey of this property included: (1) a gamma scan at the ground surface in grid blocks spanning the fence line; (2) collection of soil samples; and (3) gamma profiles of selected auger holes. The radiological survey followed a general plan developed at ORNL for vicinity properties in Hazelwood and Berkeley, Missouri.[7] A comprehensive description of the survey methods and instrumentation has been presented in another report.[8]

To provide better definition of contamination, the area adjacent to the fence line was divided into grid blocks of approximately 20 × 50 ft. Each grid block encompassed an area 10 ft wide on each side of the fence line and extended laterally along it. These grid blocks are identified by the coordinates of the intersection of the master grid lines (50 × 50 ft) with the fence line. Accessible areas in each grid block inside and outside the fence line were scanned with the portable gamma scintillation meter, and the range of measurements found within the block was recorded. Additionally, soil samples were taken from the surface at systematically selected locations and from auger holes drilled in regions of suspected contamination. The samples were analyzed for ^{238}U, ^{226}Ra, and ^{232}Th content. To avoid duplication of effort, soil data from samples taken at the fence line during the survey along Latty Avenue[5] augments the sample data collected for this report.

To define the extent of subsurface soil contamination, the auger holes were drilled to depths of approximately 2.4 m. A plastic pipe was placed in each hole, and a NaI scintillation probe was lowered inside the pipe. The probe was encased in a lead shield with a horizontal row of collimating slits on the side. This collimation allows measurement of gamma radiation intensities resulting from contamination within small fractions of the hole depth. When possible, if the gamma readings in the hole were not uniform, a soil sample was scraped from the wall of the auger hole at the point showing the highest gamma radiation level. The auger hole loggings were used to select locations where further soil sampling would be useful. At points as close as practical to several selected auger holes, a split-spoon sampler was used to collect subsurface samples at known depths.

SURVEY RESULTS

Applicable federal guidelines for radiation exposure to the general public from residual contaminants in soil are given in Table 1. Typical background radiation levels for the St. Louis area are presented in Table 2. These data are provided for purposes of comparison with the survey results reported in this section.

All measurements presented in this report are gross readings; background radiation levels have not been subtracted. Similarly, background concentrations have not been subtracted from radionuclide concentrations in soil samples.

GAMMA MEASUREMENTS

Results of grid block measurements are given in Table 3. The gamma exposure rates measured on this property were generally elevated, ranging from near background levels to 200 times background. Gamma levels ranged from 6 to 960 μR/h inside the fence line, and from 6 to 1200 μR/h outside the fence line. The maximum gamma exposure rate measured, 1200 μR/h, was located at grid location 8+77, 700R at the eastern property line.

SURFACE SOIL SAMPLING

The results of radionuclide analyses of 51 systematic surface (0 to 15 cm) soil samples are given in Table 4. The sampling locations are shown on Fig. 2. Concentrations of ^{226}Ra and ^{238}U in systematic samples ranged from 0.86 to 1700 pCi/g and 0.81 to 1200 pCi/g, respectively. Concentrations of ^{230}Th ranged from 9.5 to 77,000 pCi/g. The maximum concentration of each radionuclide was found in sample 49 taken from near the fence line along Latty Avenue. In general, the three radionuclides were found in higher concentrations in surface samples than in subsurface (auger hole) samples.

SUBSURFACE INVESTIGATIONS

Varying thicknesses of subsurface soil were sampled from depths of 0 to 215 cm in auger holes which were drilled at 38 separate locations as shown on Fig. 3. The results of analysis are given in Table 5. Concentrations of ^{226}Ra and ^{238}U in soil samples from auger holes ranged from 0.66 to 560, and 0.28 to 610 pCi/g, respectively. Concentrations of ^{230}Th ranged from less than 0.99 to 16,000 pCi/g. The maximum concentrations of each radionuclide were found in holes 10, 11, and 160 in samples from the top 30 cm of soil.

Gamma logging was performed in each of 13 selected holes to characterize and further define the extent of contamination. The logging technique used here is not radionuclide specific. However, the logging data, in conjunction with the soil analyses data, may be used to estimate the region of contamination in the auger holes. It appears from a comparison of these data that a reading of 1000 cpm or greater using the shielded scintillator indicates the presence of elevated concentrations of ^{226}Ra and/or ^{238}U. Consequently, soil giving rise to 1000 cpm or greater on the scintillator or containing radionuclide concentrations above criteria (Table 1) as determined from soil analysis was considered as contaminated soil. Using these criteria, an estimate of the region of contamination in each hole was made. These data are listed in Table 6. A word of caution should be added in the

interpretation of the data presented in Table 6. Only those holes yielding a positive indication of contamination, using the previously stated criteria, are listed as having a region of contamination; an entry of "none" opposite a location means only that no positive indication of contamination was observed using the "logging" and sampling procedures employed on this site. Because of the difficulty of detecting ^{230}Th with this in-situ hole logging device, concentrations of ^{230}Th in the absence of ^{226}Ra considerably in excess of 5 pCi/g may have gone undetected. Graphical representations of the gamma profiles of the logged auger holes are presented in the appendix.

The maximum depth at which contamination was measured was 1.7 m. In general, radionuclide concentrations decreased with increase in depth. The maximum contamination was measured at an average depth of 0.36 m.

SIGNIFICANCE OF FINDINGS

A summary of the measurement results of the radiological survey conducted on this property is provided in Table 7. These results demonstrate the presence of contamination over the major portion of the fence line area. The gamma exposure levels near the ground surface ranged from 6 to 1200 μR/h, with 53 of 55 grid blocks having exposure rates above background. Typical background for the St. Louis area ranges from 5 to 8 μR/h, averaging 6 μR/h.

The results of soil analysis establish the presence of ^{226}Ra, ^{238}U, and ^{230}Th contamination over a large portion of the surveyed area. The maximum concentrations of ^{226}Ra, ^{230}Th, and ^{238}U in soil were 1700, 77,000, and 1200 pCi/g, respectively, and were found in a sample taken from the surface (0 to 15 cm). Of the 183 subsurface soil samples, 126 had concentrations of ^{226}Ra and ^{238}U exceeding the range of typical background concentrations for the St. Louis area. In those samples, the activity of ^{226}Ra and ^{238}U was roughly equal, indicating secular equilibrium which is characteristic of uranium ore material. This relationship was generally observed in surface soil as well. The elevated concentrations of ^{230}Th seen in most soil samples are typical of the wastes and residues that had been stored at this site. The average concentrations of ^{226}Ra and ^{230}Th in surface soil exceed the U.S. DOE guideline of 5 pCi/g by factors of approximately 22 and 840, respectively. The contamination was found to extend to depths of 1.7 m and appeared to be most highly concentrated in the soil layer sampled at 0.36 m.

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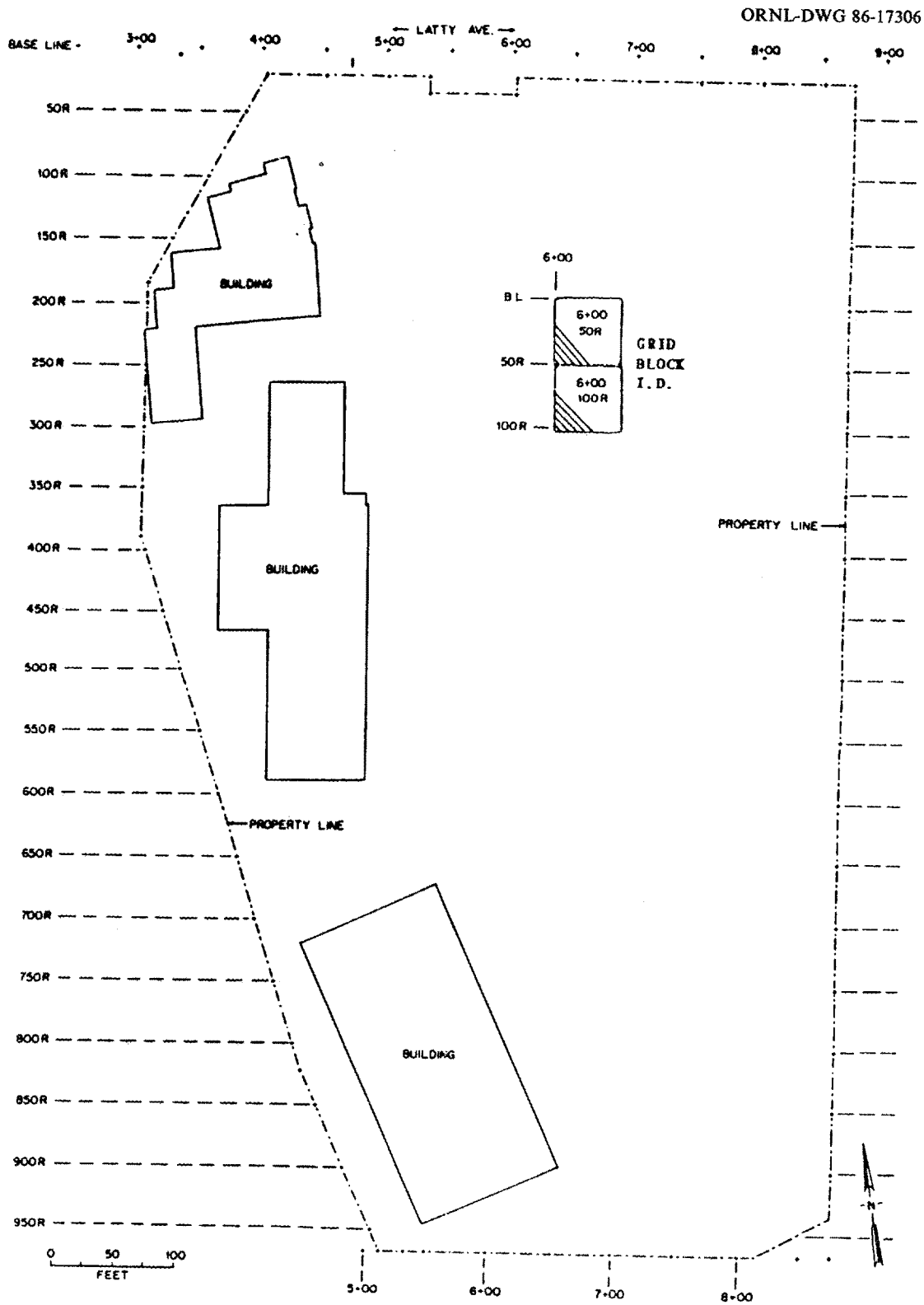

Fig. 1. Drawing showing grid lines along the perimeter fence line of the former Cotter site (LM002).

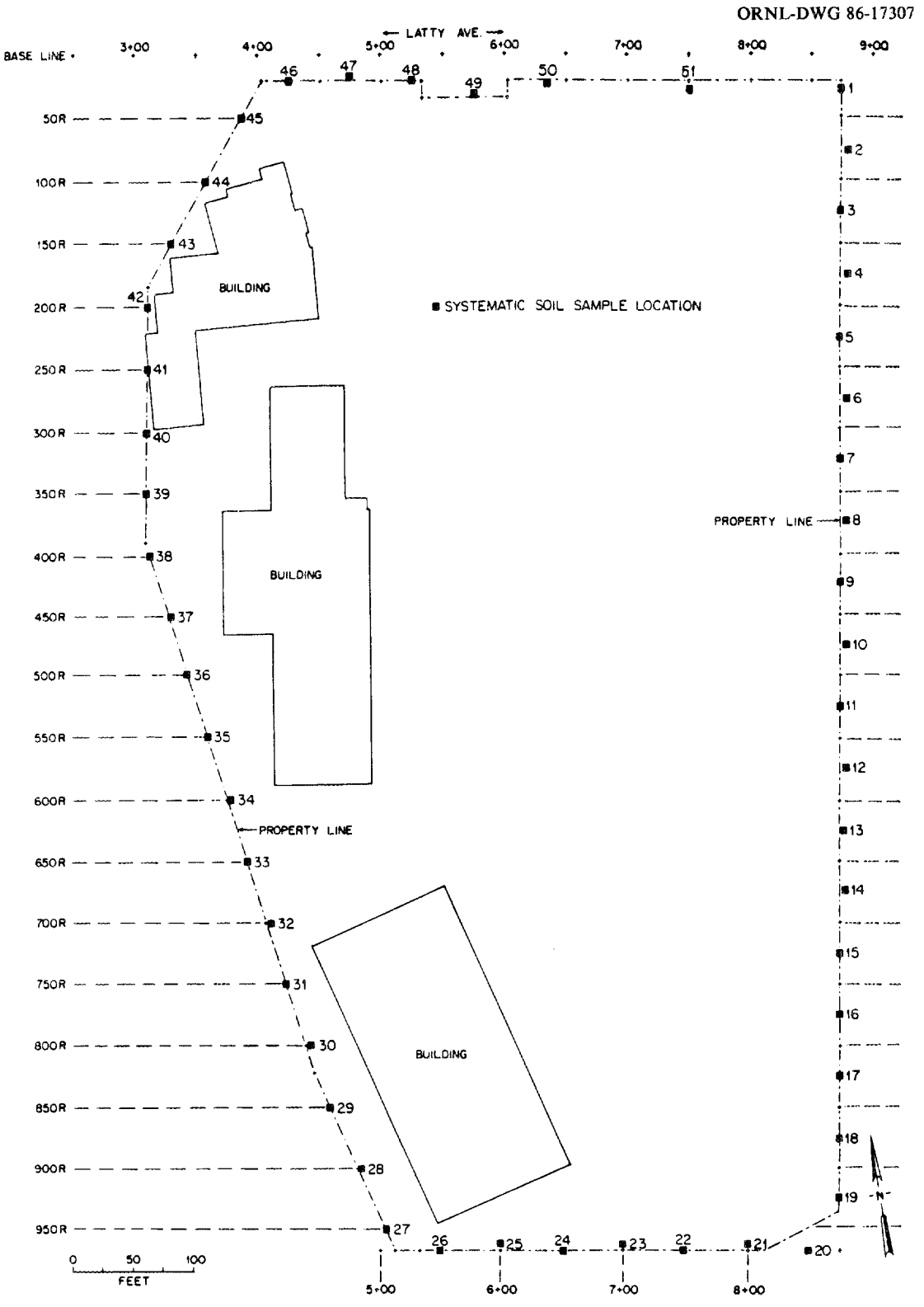

Fig. 2. Locations of surface soil samples taken along the perimeter fence line of the former Cotter site (LM002).

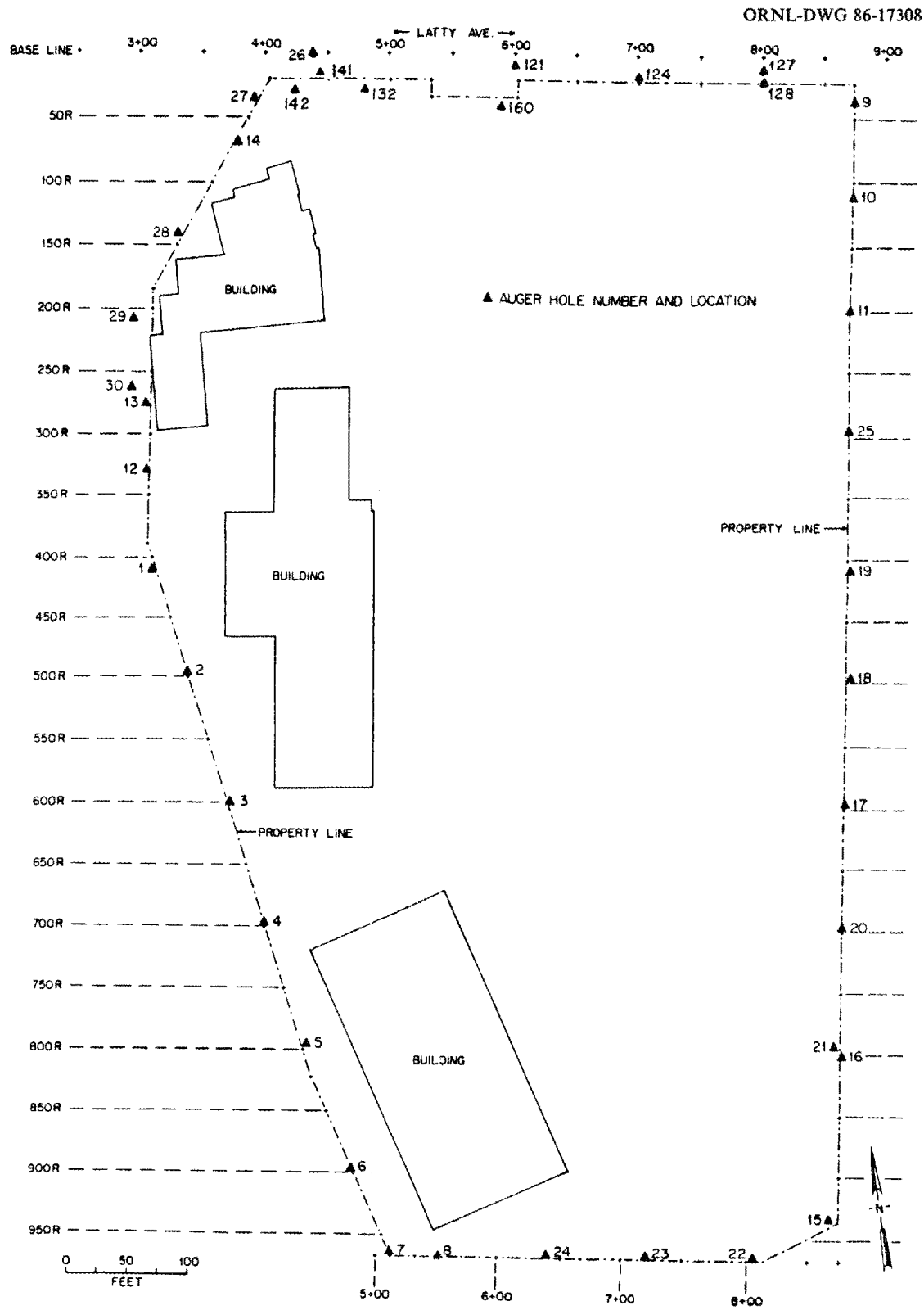

Fig. 3. Locations of subsurface soil samples taken along the perimeter fence line of the former Cotter site (LM002).

Table 1. Applicable guidelines for protection against radiation[a]

Mode of exposure	Exposure conditions	Guideline value
Radionuclide concentrations in soil	Maximum permissible concentration of the following radionuclides in soil above background levels averaged over 100 m^2 area ^{232}Th ^{230}Th ^{228}Ra ^{226}Ra	5 pCi/g averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over 15-cm thick soil layers more than 15 cm below the surface

[a]U.S. Department of Energy Guidelines for Residual Radioactivity at Formerly Utilized Sites Remedial Action Program and Remote Surplus Facilities Management Program Sites (July 1985).

Table 2. Background radiation levels in the St. Louis area[a]

Type of radiation measurement or sample	Radiation level or radionuclide concentration	
	Range	Average
Gamma exposure rate at 1 m above floor or ground surface (μR/h)[b]	5–8	6
Concentration of radionuclides in soil (pCi/g)[c]		
^{238}U	0.33–1.2	0.91
^{226}Ra	0.31–1.3	0.96
^{230}Th[d]	0.33–1.2	0.91

[a]Ref. 9.

[b]Values obtained from seven locations in eastern Missouri.

[c]Soil samples (MO3, MO4, and MO6-MO10) obtained from seven locations in eastern Missouri.

[d]^{230}Th assumed to be in equilibrium with ^{238}U.

Table 3. Results of gamma exposure rate measurements taken along the perimeter fence line of the former Cotter Site (LM002)

Grid location[a]	Range of gamma exposure rates during scan of grid block (μR/h)	
	Inside fence	Outside fence
8+77, BL	16–56	13–40
8+77, 50R	32–290	19–130
8+77, 100R	160–720	130–400
8+77, 150R	240–640	110–400
8+77, 200R	130–400	110–400
8+77, 250R	80–320	80–800
8+77, 300R	80–400	110–640
8+77, 350R	80–320	64–640
8+77, 400R	80–400	80–960
8+77, 450R	64–190	96–640
8+77, 500R	40–160	48–190
8+77, 550R	24–64	40–110
8+77, 600R	24–240	24–110
8+77, 650R	16–48	22–160
8+77, 700R	16–800	64–1200
8+77, 750R	40–400	16–64
8+77, 800R	32–240	16–80
8+77, 850R	13–32	13–160
8+77, 900R	10–96	10–16
8+00, 966R	24–110	16–240
7+50, 966R	32–240	64–640
7+00, 966R	32–210	48–290
6+50, 966R	26–140	19–340
6+00, 966R	22–70	24–120
5+50, 966R	26–210	32–100
5+14, 966R	22–32	11–32
5+06, 950R	24–40	10–32
4+84, 900R	13–29	8–32
4+63, 850R	19–35	11–160
4+44, 800R	16–42	19–190
4+27, 750R	10–29	13–160
4+11, 700R	10–16	11–64
3+95, 650R	9–19	11–120
3+78, 600R	8–19	10–61
3+62, 550R	8–19	11–40
3+46, 500R	9–19	13–19
3+30, 450R	8–19	10–32
3+14, 400R	6–16	6–16

Table 3 (continued)

Grid location[a]	Range of gamma exposure rates during scan of grid block (μR/h)	
	Inside fence	Outside fence
3+09, 350R	6–8	6–8
3+09, 300R	6–7	6–8
3+09, 250R	7–8	6–10
3+09, 200R	7–8	8–13
3+09, 182R	8–10	8–11
3+28, 150R	7–22	9–16
3+54, 100R	10–19	10–24
3+84, 50R	11–14	11–24
4+05, 20R	11–160	11–160
5+35, 35R	56–960	56–800
6+03, 35R	24–240	96–480
6+50, 20R	16–24	24–35
7+00, 20R	19–24	24–32
7+50, 20R	19–24	19–24
8+00, 20R	13–19	19–24
8+50, 20R	14–19	16–19

[a]Grid locations are shown on Fig. 1. These coordinates identify the grid block surveyed from the location given, clockwise along the perimeter fence line, to the next intersection of a master grid line with the fence, ~50 ft.

Table 4. Radionuclide concentrations in surface soil samples taken along the perimeter fence line of the former Cotter Site (LM002)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
		Systematic samples[e]			
1	8+74, 25R	0–15	4.3 ± 0.4	170	3.9
2	8+80, 75R	0–15	3.1 ± 0.2	100	3.0
3	8+74, 125R	0–15	920 ± 90	45,000	1,000
4	8+80, 175R	0–15	270 ± 10	13,000	300
5	8+74, 225R	0–15	160 ± 5	7,200	170
6	8+80, 275R	0–15	150 ± 10	6,300	190
7	8+74, 325R	0–15	430 ± 30	18,000	520
8	8+80, 375R	0–15	19 ± 0.7	1,000	17
9	8+74, 425R	0–15	40 ± 0.4	1,700	35
10	8+80, 475R	0–15	430 ± 10	16,000	480
11	8+74, 125R	0–15	46 ± 2	2,100	38
12	8+80, 575R	0–15	34 ± 2	1,100	33
13	8+74, 625R	0–15	29 ± 1	1,100	35
14	8+80, 675R	0–15	4.5 ± 0.1	150	7.8
15	8+74, 725R	0–15	47 ± 2	1,600	16
16	8+80, 775R	0–15	5.2 ± 0.3	160	2.5
17	8+74, 825R	0–15	31 ± 3	860	5.5
18	8+80, 875R	0–15	2.3 ± 0.3	40	1.5
19	8+74, 925R	0–15	2.4 ± 0.3	59	1.6
20	8+50, 969R	0–15	2.2 ± 0.3	38	1.4
21	8+00, 963R	0–15	8.8 ± 0.7	300	2.9
22	7+50, 969R	0–15	660 ± 20	5,900	74
23	7+00, 963R	0–15	4.9 ± 0.4	150	2.1
24	6+50, 969R	0–15	640 ± 20	5,400	59
25	6+00, 963R	0–15	13 ± 1	500	7.5
26	5+50, 969R	0–15	22 ± 1	900	15
27	5+03, 950R	0–15	15 ± 1	590	12
28	4+87, 900R	0–15	10 ± 0.6	240	7.2
29	4+60, 850R	0–15	7.1 ± 0.2	130	20
30	4+47, 800R	0–15	23 ± 1	860	20
31	4+42, 750R	0–15	14 ± 1	380	11
32	4+14, 700R	0–15	4.9 ± 0.6	160	4.6
33	3+92, 650R	0–15	1.4 ± 0.09	41	1.8
34	3+81, 600R	0–15	1.9 ± 0.1	42	2.6

Table 4 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
35	3+59, 550R	0–15	4.0 ±0.2	140	3.4
36	3+49, 500R	0–15	3.5 ±0.5	130	3.9
37	3+27, 450R	0–15	4.5 ±0.4	160	4.5
38	3+17, 400R	0–15	2.8 ±0.5	99	3.0
39	3+06, 350R	0–15	1.5 ±0.1	19	1.4
40	3+12, 300R	0–15	0.86±0.03	9.5	0.81
41	3+00, 250R	0–15	1.6 ±0.05	32	1.3
42	3+12, 200R	0–15	1.6 ±0.2	18	1.3
43	3+25, 150R	0–15	1.7 ±0.06	24	1.5
44	3+57, 100R	0–15	11 ±0.3	420	7.5
45	3+81, 50R	0–15	5.0 ±1	180	4.8
46	4+25, 23R	0–15	6.0 ±0.5	250	4.7
47	4+75, 17R	0–15	32 ±2	1,600	24
48	5+25, 23R	0–15	39 ±3	1,800	28
49	5+75, 32R	0–15	1,700 ±80	77,000	1,200
50[f]	6+39, 22R	0–15	2.2 ±0.1	62	4.0
51[f]	7+50, 28R	0–15	1.5 ±0.04	27	1.4

[a]Locations of soil samples are shown on Fig. 2.

[b]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).

[c]The error of the reported radionuclide concentration is less than ±5% (95% confidence level).

[d]Total error of measurement results is less than ±3% (95% confidence level).

[e]Systematic samples are taken at grid locations irrespective of gamma exposure.

[f]Systematic surface soil samples 50 and 51 correspond to samples 34 and 33, respectively, from companion report.[5]

Table 5. Radionuclide concentrations in subsurface soil samples taken along the perimeter fence line of the former Cotter Site (LM002)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
		Auger samples[e]			
1A	3+15, 412R	0–30	8.1±0.5	270	8.8
B		30–60	7.4±0.4	220	6.5
C		60–90	1.5±0.04	3.6	1.1
D		90–120	1.5±0.1	4.0	1.0
E		120–130	1.4±0.2	3.9	1.1
F		145–165	1.4±0.05	2.9	0.97
2A	3+46, 499R	0–30	4.5±0.3	120	4.5
B		30–60	5.7±0.4	150	4.8
C		60–90	2.1±0.06	27	1.4
D		90–120	7.1±0.6	260	5.9
E		120–145	1.6±0.03	31	1.6
F		145–165	1.6±0.2	4.8	1.0
3A	3+80, 600R	0–30	4.1±0.2	110	3.8
B		30–60	2.0±0.1	41	1.7
C		60–90	1.5±0.2	16	1.4
D		90–120	5.6±0.5	160	6.2
E		120–145	1.4±0.4	3.3	1.9
F		145–165	1.4±0.4	3.5	2.4
4A	4+11, 699R	0–30	3.3±0.3	77	4.2
B		30–60	3.1±0.3	72	5.1
C		60–90	1.3±0.2	<1.8	1.9
D		90–120	1.4±0.2	<2.7	1.1
E		120–130	1.3±0.1	<3.2	1.1
F		145–165	1.3±0.1	<4.1	1.0
5A	4+46, 798R	0–30	2.1±0.1	28	3.1
B		30–60	1.4±0.2	<1.4	1.2
C		60–90	2.0±0.3	14	1.5
D		90–120	1.5±0.2	<1.8	1.1
E		120–145	1.4±0.1	<4.1	1.0
F		145–165	1.3±0.05	14	0.99
6A	4+50, 905R	0–30	11 ±0.4	310	17
B		30–60	22 ±0.7	900	17
C		60–90	5.6±0.2	120	9.3
D		90–120	7.7±0.2	210	6.1
E		120–150	1.3±0.1	12	1.7
F		150–185	1.3±0.05	<4.1	1.5
G		185–215	1.3±0.1	<1.8	1.2

Table 5 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
7A	5+15, 965R	0–30	34 ± 1	1,800	21
B		30–60	5.7 ± 0.3	240	7.4
C		60–90	8.4 ± 0.4	16	9.5
D		90–120	5.5 ± 0.3	<4.5	6.4
E		120–150	2.9 ± 0.1	12	3.5
F		150–185	1.6 ± 0.1	<3.2	1.8
G		185–215	1.1 ± 0.1	<1.8	1.4
8A	5+51, 966R	0–30	9.3 ± 0.4	270	3.8
B		30–60	7.2 ± 0.6	190	3.2
C		60–90	7.3 ± 0.4	180	3.7
D		90–120	1.3 ± 0.3	8.4	1.7
E		120–150	1.1 ± 0.04	2.4	1.0
F		150–185	1.2 ± 0.1	3.3	1.1
G		185–215	1.3 ± 0.1	2.5	0.98
9A	8+74, 36R	0–30	3.6 ± 0.3	100	3.6
B		30–60	1.2 ± 0.3	3.1	1.1
C		60–90	1.2 ± 0.3	2.6	1.0
D		90–120	1.1 ± 0.1	3.1	0.94
E		120–145	1.2 ± 0.1	2.8	1.1
F		145–165	1.1 ± 0.05	2.4	0.95
10A	8+74, 113R	0–30	560 ± 30	1,800	610
B		30–60	6.4 ± 0.2	26	11
C		60–90	2.2 ± 0.2	32	3.4
D		90–120	5.8 ± 0.5	190	6.6
E		120–150	1.4 ± 0.1	5.4	0.91
F		150–185	1.3 ± 0.2	3.4	0.87
11A	8+74, 202R	0–30	470 ± 20	37	610
B		30–60	1.7 ± 0.1	45	5.2
C		60–90	1.5 ± 0.06	6.4	4.0
D		90–120	1.9 ± 0.08	20	2.4
E		120–145	3.3 ± 0.2	150	3.5
F		145–165	1.7 ± 0.06	450	1.7
12A	3+09, 328R	0–30	2.6 ± 0.2	90	2.4
B		30–60	1.3 ± 0.1	17	1.1
C		60–90	1.3 ± 0.2	3.3	1.1
D		90–120	1.4 ± 0.3	3.5	1.1
E		120–145	1.4 ± 0.07	3.2	1.0
F		145–165	1.4 ± 0.3	3.4	1.1

Table 5 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
13A	3+07, 276R	0–30	2.0±0.09	27	1.6
B		30–60	1.3±0.09	3.1	1.1
C		60–90	1.4±0.1	2.9	1.1
D		90–120	1.3±0.2	2.7	1.1
E		120–145	1.4±2	2.7	1.1
F		145–165	1.4±0.1	2.2	1.0
14A	3+80, 70R	0–30	5.6±0.4	170	3.5
B		30–60	3.3±0.2	60	2.7
C		60–90	1.4±0.1	11	1.4
D		90–120	1.3±0.2	2.7	1.1
E		120–150	1.4±0.08	5.7	1.2
F		150–185	1.3±0.2	3.0	1.1
G		185–215	1.3±0.07	2.2	1.1
15A	8+65, 934R	0–30	1.3±0.3	5.1	1.1
B		30–60	1.3±0.2	3.0	1.1
C		60–90	1.3±0.2	3.0	1.1
D		90–120	1.4±0.07	2.7	1.1
E		120–145	1.3±0.3	2.9	1.0
F		145–165	1.3±0.4	2.5	1.0
16A	8+74, 800R	0–30	24 ±0.8	680	3.4
B		30–60	25 ±0.6	450	2.7
C		60–90	1.3±0.1	<4.1	1.2
D		90–120	1.4±0.3	<3.6	1.2
E		120–145	1.4±0.1	<4.5	1.3
F		145–165	1.4±0.08	<5.0	1.3
17A	8+74, 594R	0–30	3.2±0.2	56	8.6
B		30–60	1.3±0.2	2.7	4.5
C		60–90	1.3±0.2	5.8	6.1
D		90–120	1.3±0.2	3.7	4.1
E		120–145	1.3±0.04	5.5	1.4
F		145–165	1.3±0.3	2.5	1.2
18A	8+76, 497R	0–30	73 ±4	2,100	97
B		30–60	1.4±0.2	9.5	4.4
C		60–90	1.5±0.3	9.3	5.2
D		90–120	1.5±0.3	7.3	2.8
E		120–150	1.3±0.2	4.5	1.4
F		150–175	1.4±0.1	5.3	1.3
G		175–195	1.3±0.2	6.9	1.2

Table 5 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
19A	8+75, 410R	0–30	50 ±3	2,100	59
B		30–60	1.4 ±0.2	7.7	13
C		60–90	1.4 ±0.1	3.3	1.6
D		90–120	1.4 ±0.3	4.9	1.2
E		120–145	1.3 ±0.1	3.1	1.1
F		145–165	1.3 ±0.2	3.2	1.1
20A	8+74, 697R	0–30	79 ±1	2,600	26
B		30–60	37 ±2	1,400	18
C		60–90	1.8 ±0.5	12	13
D		90–120	1.3 ±0.3	6.7	1.6
E		120–145	1.4 ±0.4	5.8	1.2
F		145–165	1.3 ±0.2	6.5	1.1
21A	8+69, 792R	0–30	2.3 ±0.3	25	1.4
B		30–60	1.5 ±0.08	<5.0	1.2
C		60–90	1.4 ±0.2	<3.2	1.2
D		90–120	1.4 ±0.08	<5.4	1.2
E		120–145	1.2 ±0.2	<5.0	1.1
F		145–165	1.2 ±0.2	<2.7	1.1
22A	8+05, 963R	0–30	56 ±2	1,500	11
B		30–60	1.5 ±0.3	13	1.2
C		60–90	1.2 ±0.2	5.1	1.1
D		90–120	1.4 ±0.2	4.5	1.1
E		120–145	3.4 ±0.05	49	1.4
F		145–165	1.2 ±0.06	2.7	1.0
23A	7+18, 964R	0–30	5.8 ±0.2	170	2.8
B		30–60	6.8 ±2	1,800	9.0
C		60–90	2.4 ±0.3	54	1.2
D		90–120	1.5 ±0.08	14	1.2
E		120–145	1.7 ±0.5	13	1.2
F		145–165	1.4 ±0.2	8.7	1.2
24A	6+40, 964R	0–30	4.9 ±0.2	190	6.4
B		30–60	0.69 ±0.1	7.7	0.86
C		60–90	0.66 ±0.08	7.7	0.85
D		90–120	2.9 ±0.03	86	1.8
E		120–145	6.4 ±0.2	210	2.8
F		145–165	5.7 ±0.6	130	2.4
25A	8+74, 299R	0–30	1.3 ±0.04	<5.4	1.1
B		30–60	1.3 ±0.2	<4.1	1.1
C		60–90	1.5 ±0.1	8.0	1.1
D		90–120	1.4 ±0.2	2.7	1.1
E		120–145	1.3 ±0.2	<4.5	0.94
F		145–165	1.0 ±0.2	<3.2	0.92

Table 5 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
26A	4+38, BL	0–30	1.5 ±1	12	1.4
B		30–60	1.2 ±0.1	4.7	1.1
C		60–90	1.2 ±0.04	5.2	1.1
D		90–120	1.1 ±0.2	2.4	1.1
27A	3+92, 36R	0–30	2.1 ±0.3	36	2.0
B		30–60	1.3 ±0.06	4.2	1.2
C		60–90	1.2 ±0.2	2.2	1.1
D		90–120	1.2 ±0.2	2.0	1.1
28A	3+30, 140R	0–30	1.4 ±0.3	8.0	0.28
B		30–60	1.4 ±0.2	4.0	1.2
C		60–90	1.3 ±0.09	3.2	1.1
D		90–120	1.4 ±0.3	3.2	1.1
29A	2+98, 210R	0–30	1.6 ±0.2	16	1.4
B		30–60	1.5 ±0.08	4.3	1.2
C		60–90	1.3 ±0.1	4.2	1.0
D		90–120	1.4 ±0.2	2.0	1.1
30A	2+96, 264R	0–30	2.2 ±0.2	34	1.7
B		30–60	1.4 ±0.1	2.7	1.1
C		60–90	1.4 ±0.08	3.2	1.1
D		90–120	1.4 ±0.1	3.0	1.1
121A[f]	6+00, 10R	0–15	37 ±3	2,000	42
B		15–30	5.1 ±0.3	250	6.3
C		45–60	1.7 ±0.07	37	2.1
124A[f]	7+00, 19R	0–15	14 ±0.5	670	10
B		15–30	3.3 ±0.08	120	4.7
C		60–75	1.5 ±0.09	45	1.7
127A[f]	8+00, 11R	0–15	6.2 ±0.4	330	6.9
B		15–30	6.8 ±0.5	120	8.5
C		60–75	1.7 ±0.3	22	2.0
128A[f]	8+00, 20R	0–15	2.7 ±0.1	66	2.3
B		30–45	1.2 ±1	6.7	1.1
C		75–90	1.2 ±0.1	3.6	1.2
132A[f]	4+80, 29R	0–15	1.4 ±0.09	51	1.0
B		15–30	0.76 ±0.1	3.0	0.76
141A[f]	4+43, 16R	0–15	1.3 ±0.08	3.2	1.1
B		15–30	1.3 ±0.06	5.0	1.2
C		45–60	1.2 ±0.2	2.2	1.1

Table 5 (continued)

Sample	Location[a]	Depth (cm)	Radionuclide concentration (pCi/g)		
			^{226}Ra[b]	^{230}Th[c]	^{238}U[d]
142A[f]	4+25, 30R	0–15	1.6±0.3	19	1.5
B		15–30	1.3±0.1	6.3	1.2
C		45–60	1.2±0.2	0.99	1.1
160A[f]	5+88, 41R	0–15	300 ±10	16,000	240
B		90–95	1.4±0.3	12	2.9

[a]Locations of soil samples are shown on Fig. 3.

[b]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).

[c]The error of the reported radionuclide concentration is ±5% (95% confidence level).

[d]Total error of measurement results is less than ±3% (95% confidence level).

[e]Auger samples are those taken from holes drilled to further define the depth and extent of tailings material. Holes may be drilled in either contaminated or uncontaminated areas.

[f]Subsurface soil sample data from companion report.[5]

Table 6. Extent of subsurface contamination along the fence line of the former Cotter Site (LM002) as indicated by scintillation probe loggings and sample analyses

Hole	Location[a]	Depth of hole (m)	Estimated vertical extent of contaminated soil[b] (m)	Region of maximum contamination (m)	Radionuclide concentration in region of maximum contamination (pCi/g)		
					^{226}Ra[c]	^{230}Th[d]	^{238}U[e]
1	3+15, 412R	1.7	0–1	0–0.3	8.1 ± 0.5	270	8.8
2	3+46, 499R	1.8	0–1.6	0.9–1.2	7.1 ± 0.6	260	5.9
3	3+80, 600R	1.7	0–1.3	0.9–1.2	5.6 ± 0.5	160	6.2
4	4+11, 699R	1.7	0–0.7	0–0.3	3.3 ± 0.3	77	4.2
5	4+46, 798R	1.7	0–1.7	0–0.3	2.1 ± 0.1	28	3.1
6	4+50, 905R	2.2	0–1.5	0.3–0.6	22 ± 0.7	900	17
7	5+15, 965R	2.2	0–1.6	0–0.3	34 ± 1	1,800	21
8	5+51, 966R	2.2	0–1.2	0–0.3	9.3 ± 0.4	270	3.8
9	8+74, 36R	1.7	0–0.3	0–0.3	3.6 ± 0.3	100	3.6
10	8+74, 113R	1.8	0–1.7	0–0.3	560 ± 30	1,800	610
11	8+74, 202R	1.6	0–1.6	0–0.3	470 ± 20	37	610
12	3+09, 328R	1.6	0–0.6	0–0.3	2.6 ± 0.2	90	2.4
13	3+07, 276R	1.8	0–0.3	0–0.3	2 ± 0.09	27	1.6
14	3+80, 70R	2.2	0–0.9	0–0.3	5.6 ± 0.4	170	3.5
15	8+65, 934R	1.6	0–0.3	0–0.3	1.3 ± 0.3	5.1	1.1
16	8+74, 800R	1.6	0–0.6	0–0.3	24 ± 0.8	680	3.4
17	8+74, 594R	1.6	0–0.3	0–0.3	3.2 ± 0.2	56	8.6
18	8+76, 497R	2	0–0.3	0–0.3	73 ± 4	2,100	97
19	8+75, 410R	1.6	0–0.3	0–0.3	50 ± 3	2,100	59
20	8+74, 697R	1.6	0–0.9	0–0.3	79 ± 1	2,600	26
21	8+69, 792R	1.6	0–0.3	0–0.3	2.3 ± 0.3	25	1.4
22	8+05, 963R	1.6	0–1.4	0–0.3	56 ± 2	1,500	11
23	7+18, 964R	1.6	0–1.5	0.3–0.6	6.8 ± 2	1,800	9
24	6+40, 964R	1.6	0–1.6	1.2–1.4	6.4 ± 0.2	210	2.8
25	8+74, 299R	1.6	None				
26	4+38, BL	1.2	0–0.3	0–0.3	1.5 ± 1	12	1.4
27	3+92, 36R	1.2	0–0.3	0–0.3	2.1 ± 0.3	36	2.0
28	3+30, 140R	1.2	0–0.3	0–0.3	1.4 ± 0.3	8	0.28
29	2+98, 210R	1.2	0–0.3	0–0.3	1.6 ± 0.2	16	1.4
30	2+96, 264R	1.2	0–0.3	0–0.3	2.2 ± 0.2	34	1.7
121[f]	6+00, 10R	1.8	0–0.90	0–0.15	37 ± 3.0	2,000	42
124[f]	7+00, 19R	1.8	0–0.90	0–0.15	14 ± 0.5	670	10
127[f]	8+00, 11R	1.5	0–0.90	0–0.15	6.2 ± 0.4	330	6.9
128[f]	8+00, 20R	1.8	0–0.30	0–0.15	2.7 ± 0.1	66	2.3
132[f]	4+80, 29R	1.8	0–0.15	0–0.15	1.4 ± 0.09	51	1.0
141[f]	4+43, 16R	1.8	None				
142[f]	4+25, 30R	1.8	0–0.15	0–0.15	1.6 ± 0.3	19	1.5
160[f]	5+88, 41R	0.9	0–0.90	0–0.15	300 ± 10	16,000	240

[a]Location of auger hole is shown on Fig. 3.

[b]Contaminated soil is defined as soil having concentrations of ^{226}Ra or $^{230}Th \geq$ the criteria given in Table 1, or scintillator logging results of ≥1000 cpm.

[c]Indicated counting error is at the 95% confidence level ($\pm 2\sigma$).

[d]The error of the reported radionuclide concentration is less than ±5% (95% confidence level).

[e]The total analytical error is less than ±5% (95% confidence level).

[f]Subsurface soil sample data from companion report.[5]

Table 7. Summary of measurements and sample results taken along the perimeter fence line of the former Cotter Site (LM002)

Measurement of sample type	Number of measurements/ samples	Range	Mean
Scan, gamma exposure rate near surface inside fence (μR/h)[a]	56	6–960	–
Scan, gamma exposure rate near surface outside fence (μR/h)[a]	56	6–1,200	–
Concentration of ^{226}Ra in surface soil (pCi/g), systematic locations[b]	51	0.86–1,700	110
Concentration of ^{230}Th in surface soil (pCi/g), systematic locations[b]	51	9.5–77,000	4,200
Concentration of ^{238}U in surface soil (pCi/g), systematic locations[b]	51	0.81–1,200	61
Concentration of ^{226}Ra in subsurface soil (pCi/g), auger hole locations[c]	197	0.66–560	3.5
Concentration of ^{230}Th in subsurface soil (pCi/g), auger hole locations[c]	197	0.99–16,000	120
Concentration of ^{238}U in subsurface soil (pCi/g), auger hole locations[c]	197	0.28–610	3.3

[a]Scan of grid blocks adjacent to fence.
[b]Systematic samples, Table 4.
[c]Auger hole samples, Table 5.

APPENDIX

GAMMA PROFILE GRAPHS OF AUGER HOLES AT PROPERTY LM002

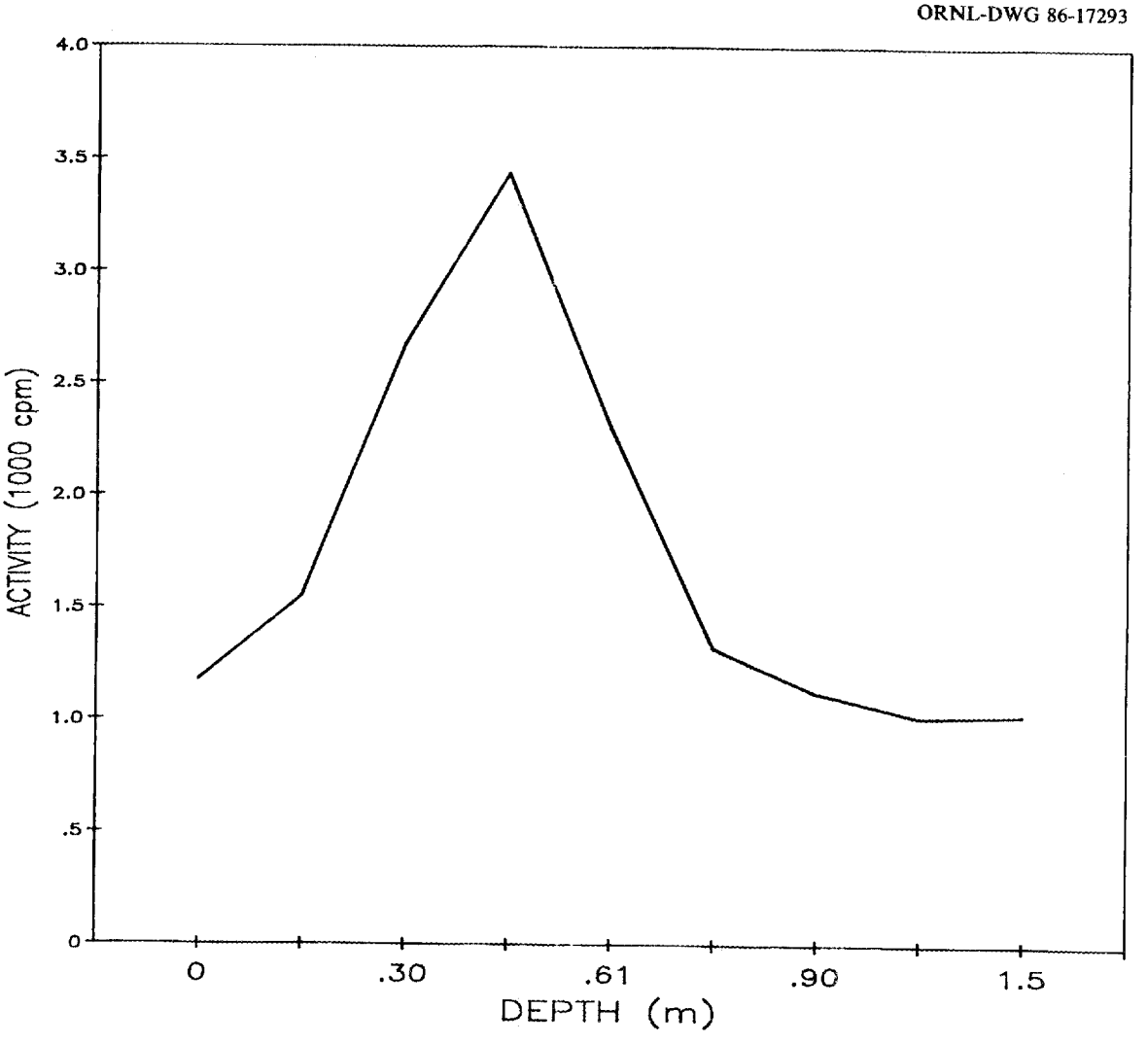

Fig. A.1. Gamma profile of auger hole 1.

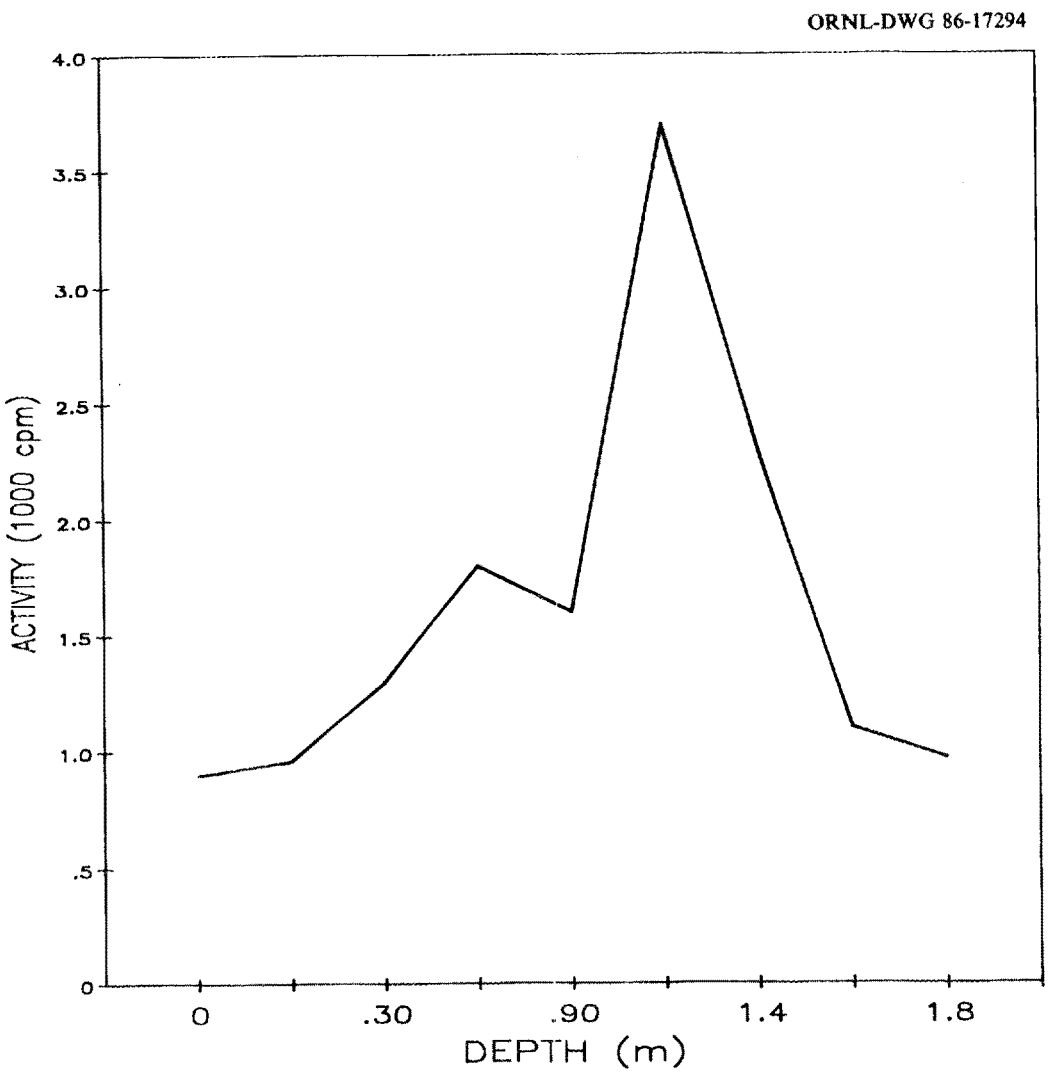

Fig. A.2. Gamma profile of auger hole 2.

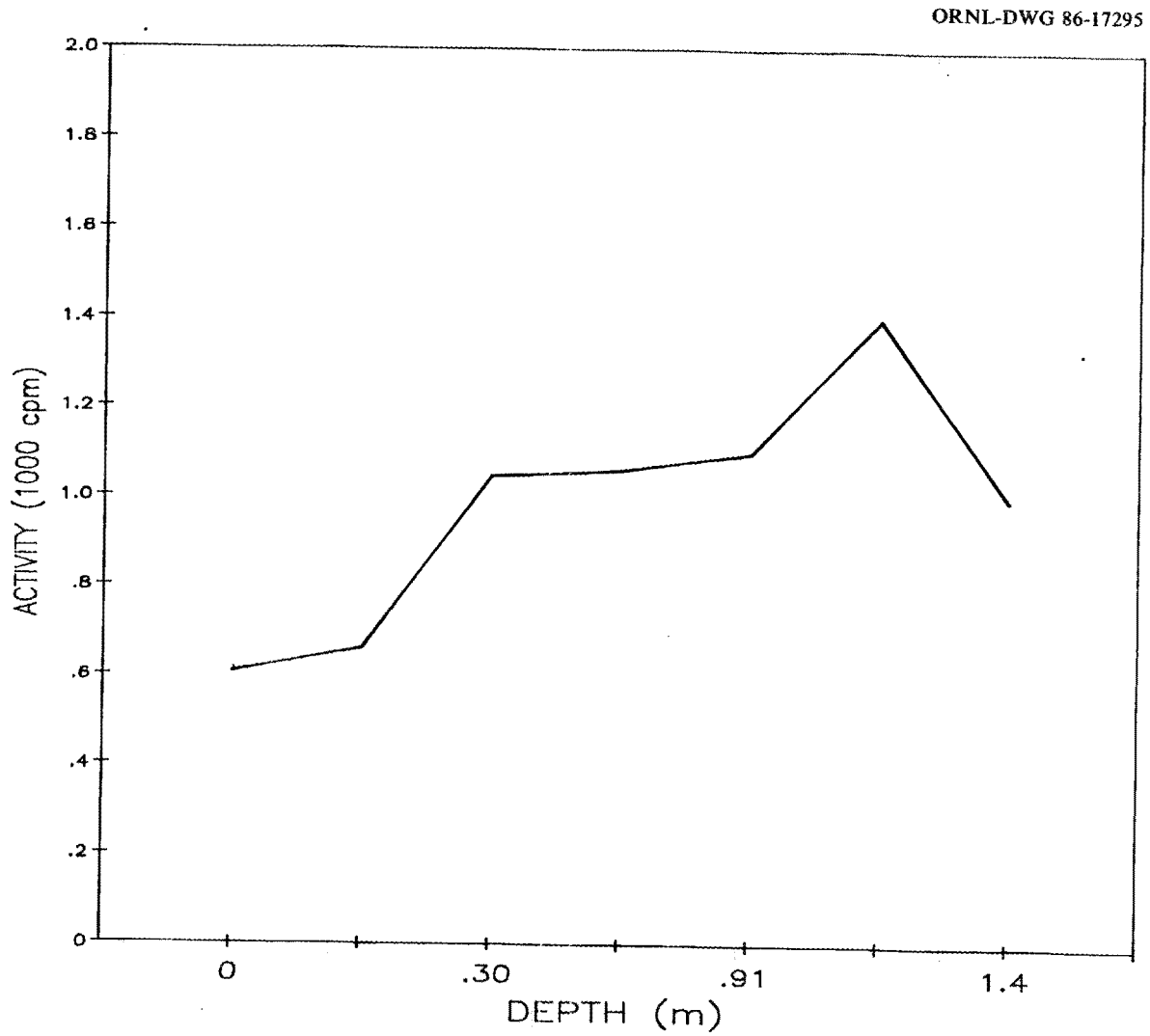

Fig. A.3. Gamma profile of auger hole 3.

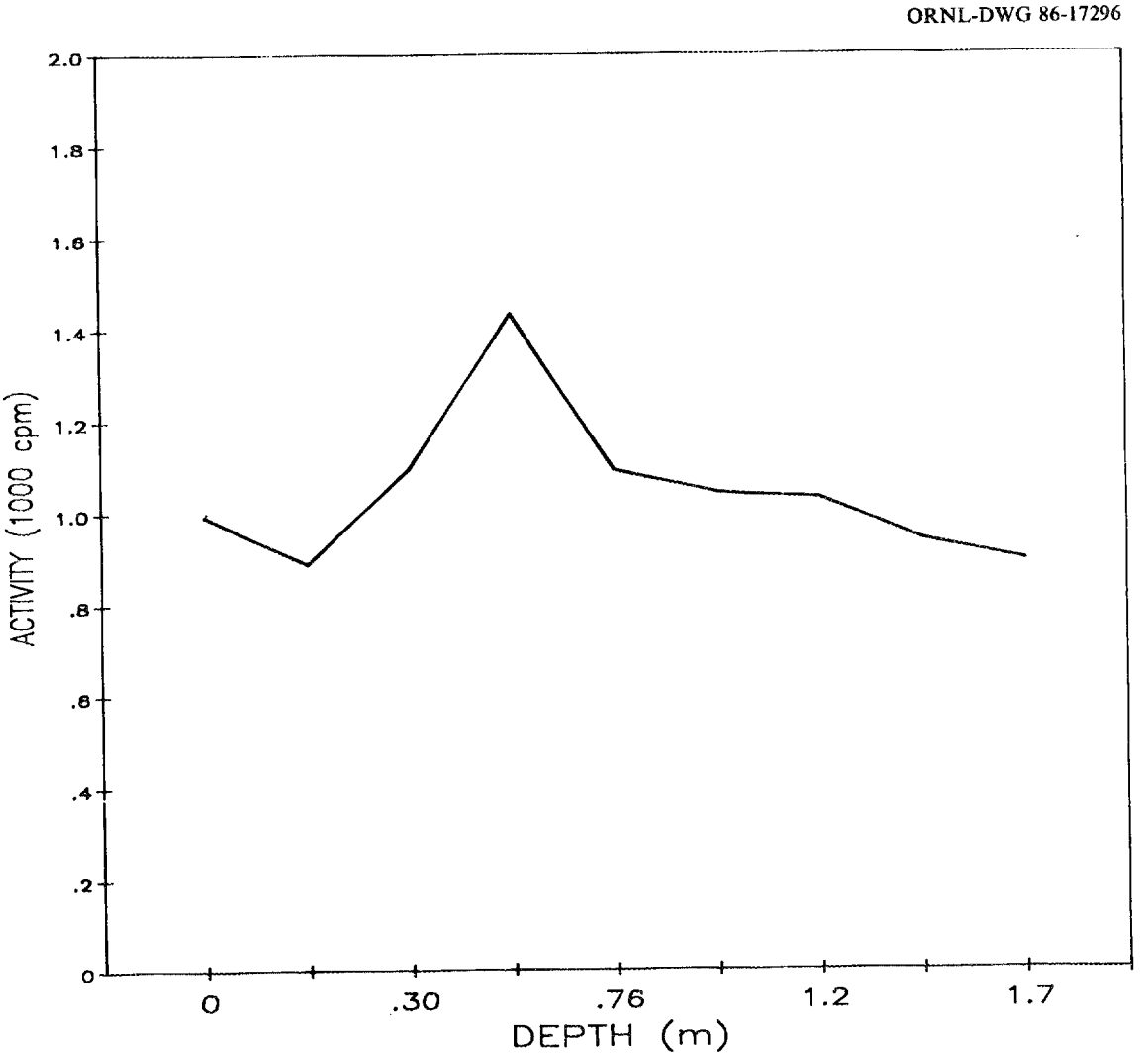

Fig. A.4. Gamma profile of auger hole 4.

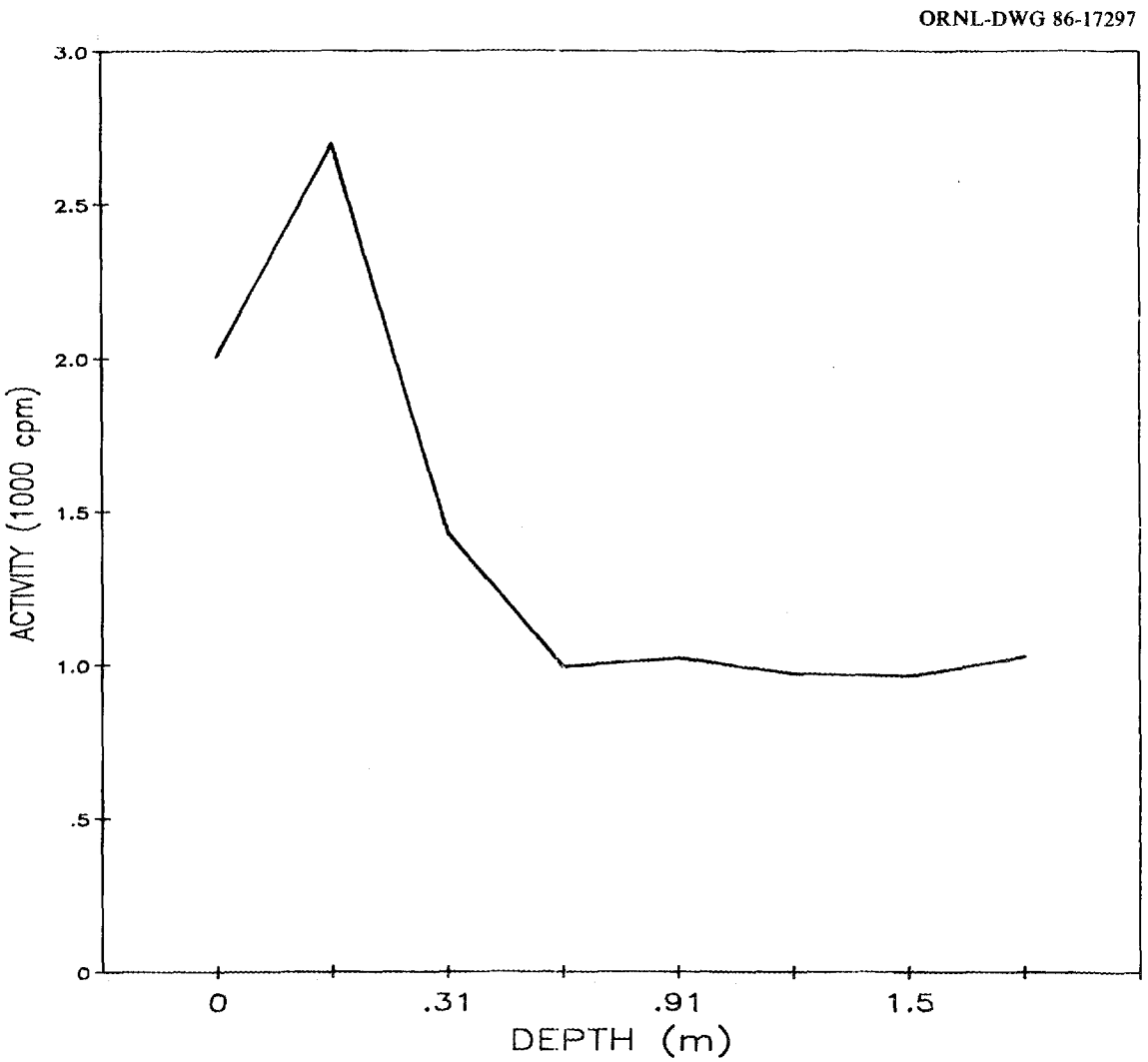

Fig. A.5. Gamma profile of auger hole 5.

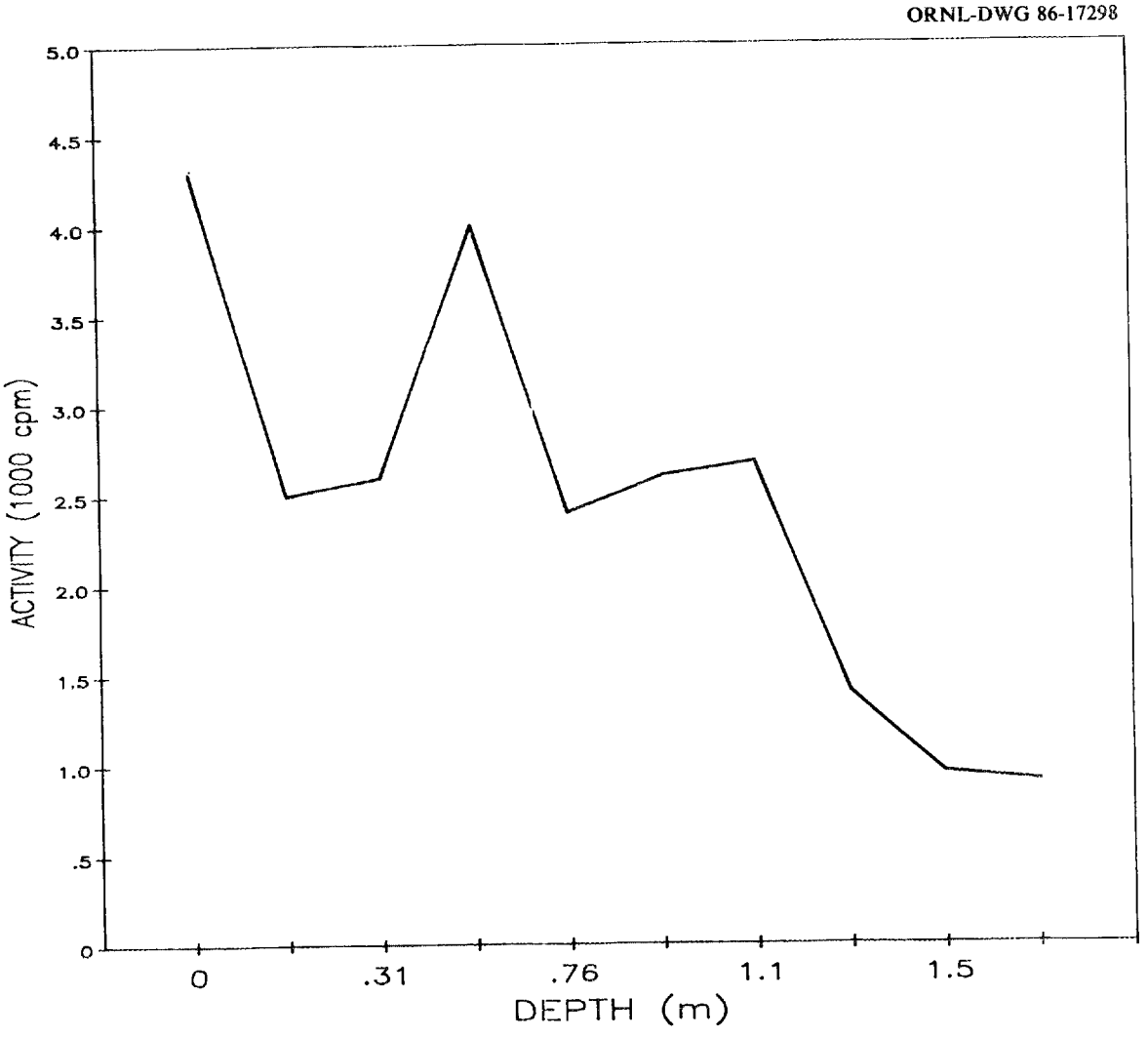

Fig. A.6. Gamma profile of auger hole 6.

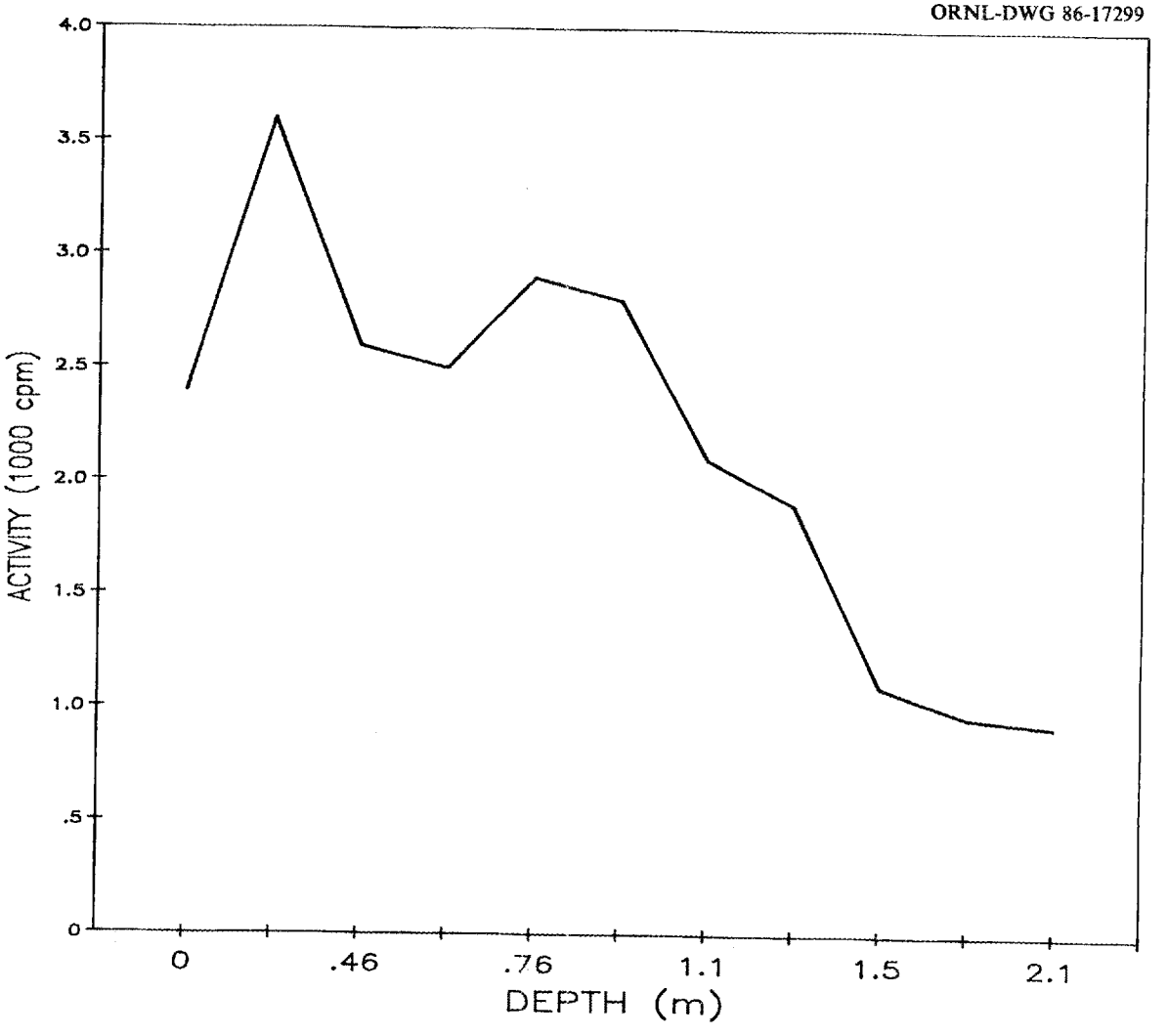

Fig. A.7. Gamma profile of auger hole 7.

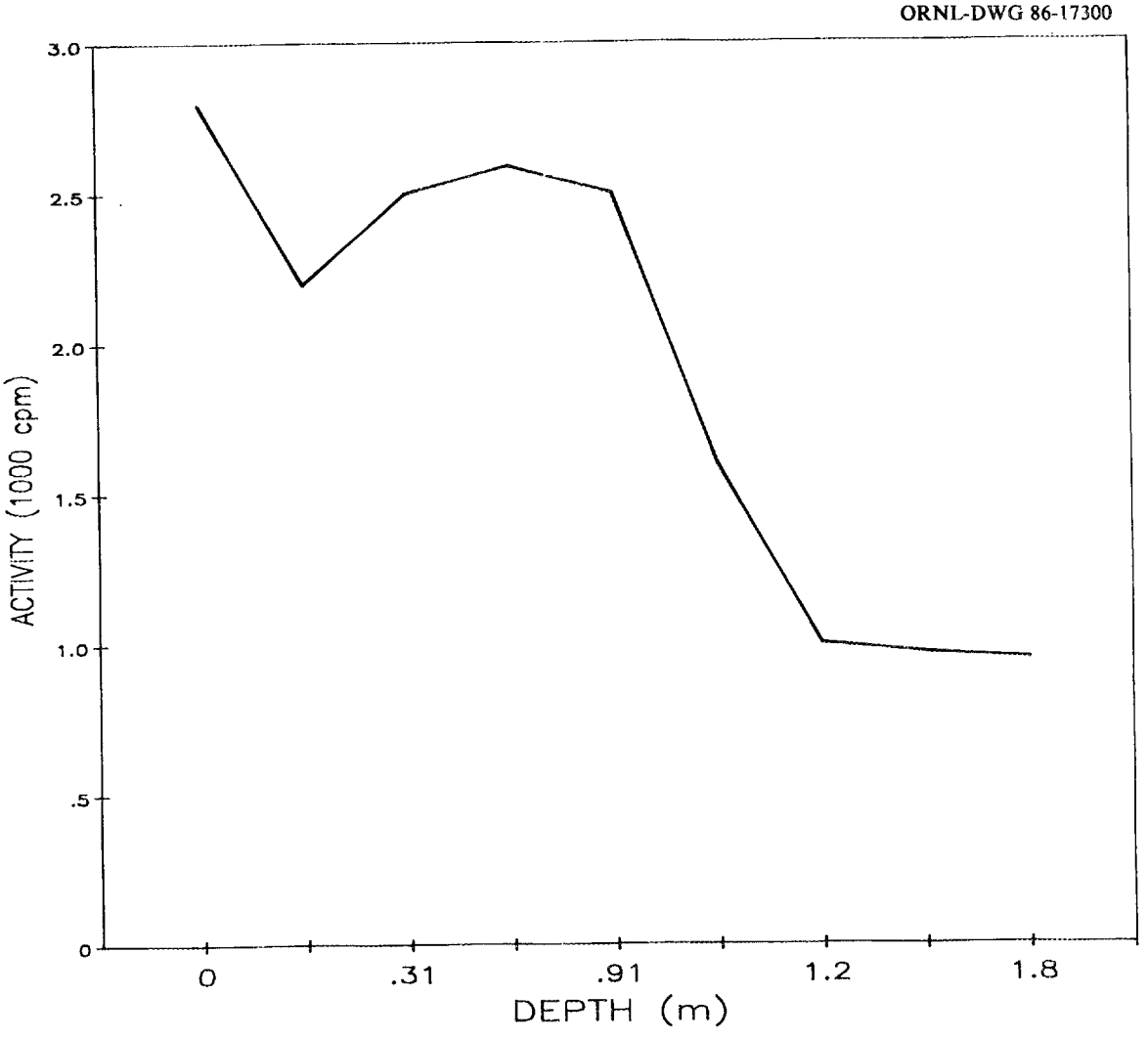

Fig. A.8. Gamma profile of auger hole 8.

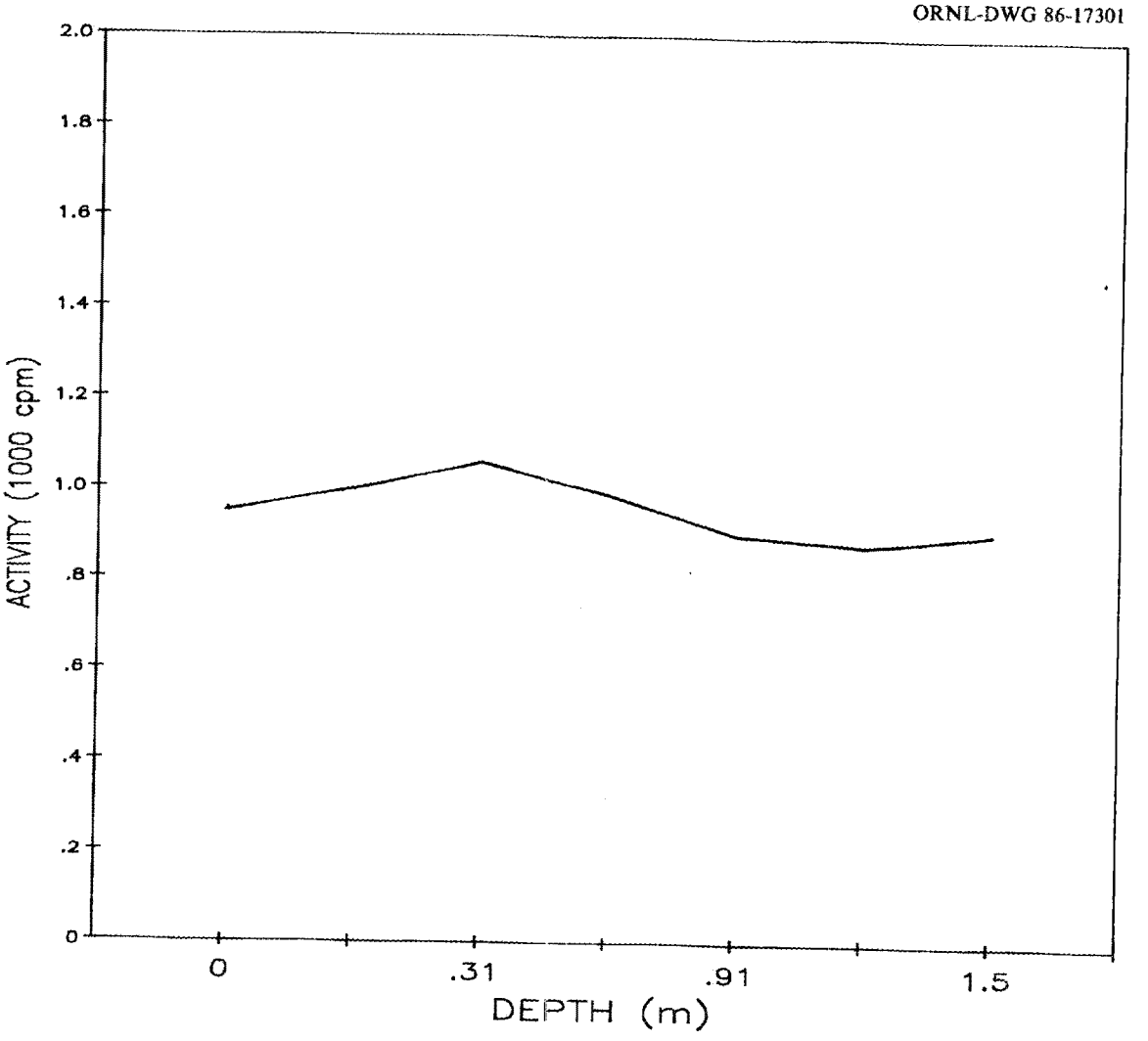

Fig. A.9. Gamma profile of auger hole 9.

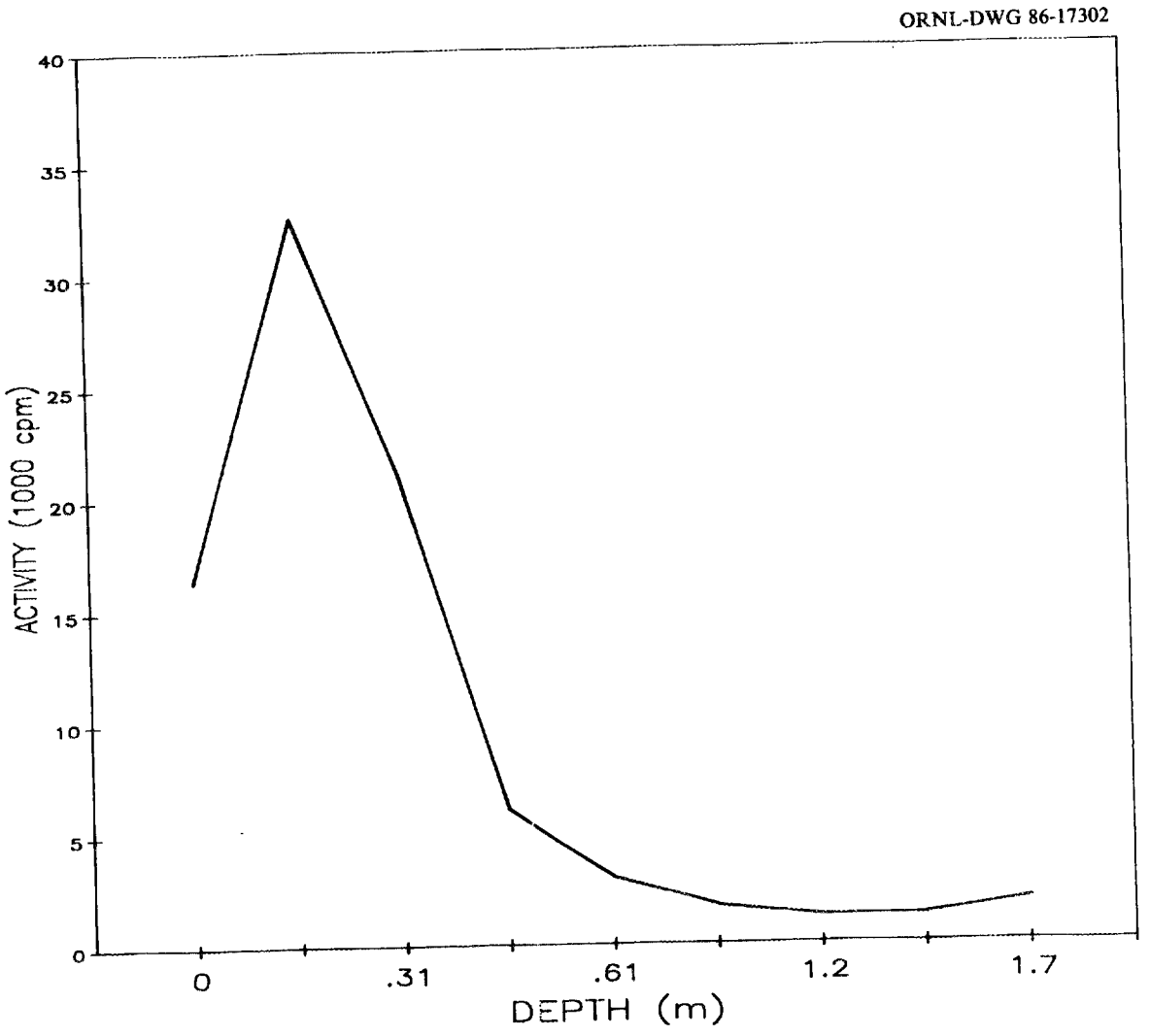

Fig. A.10. Gamma profile of auger hole 10.

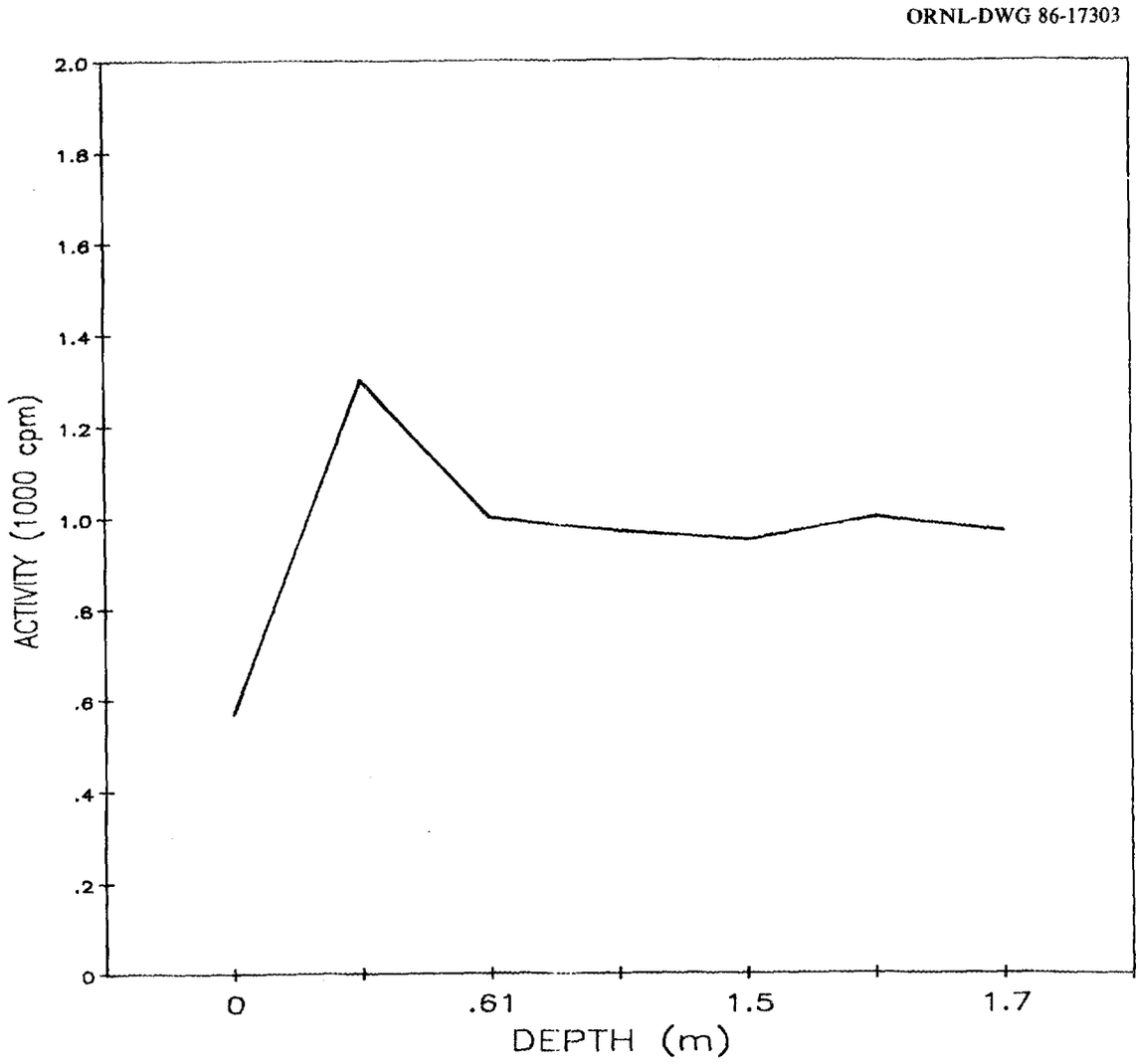

Fig. A.11. Gamma profile of auger hole 12.

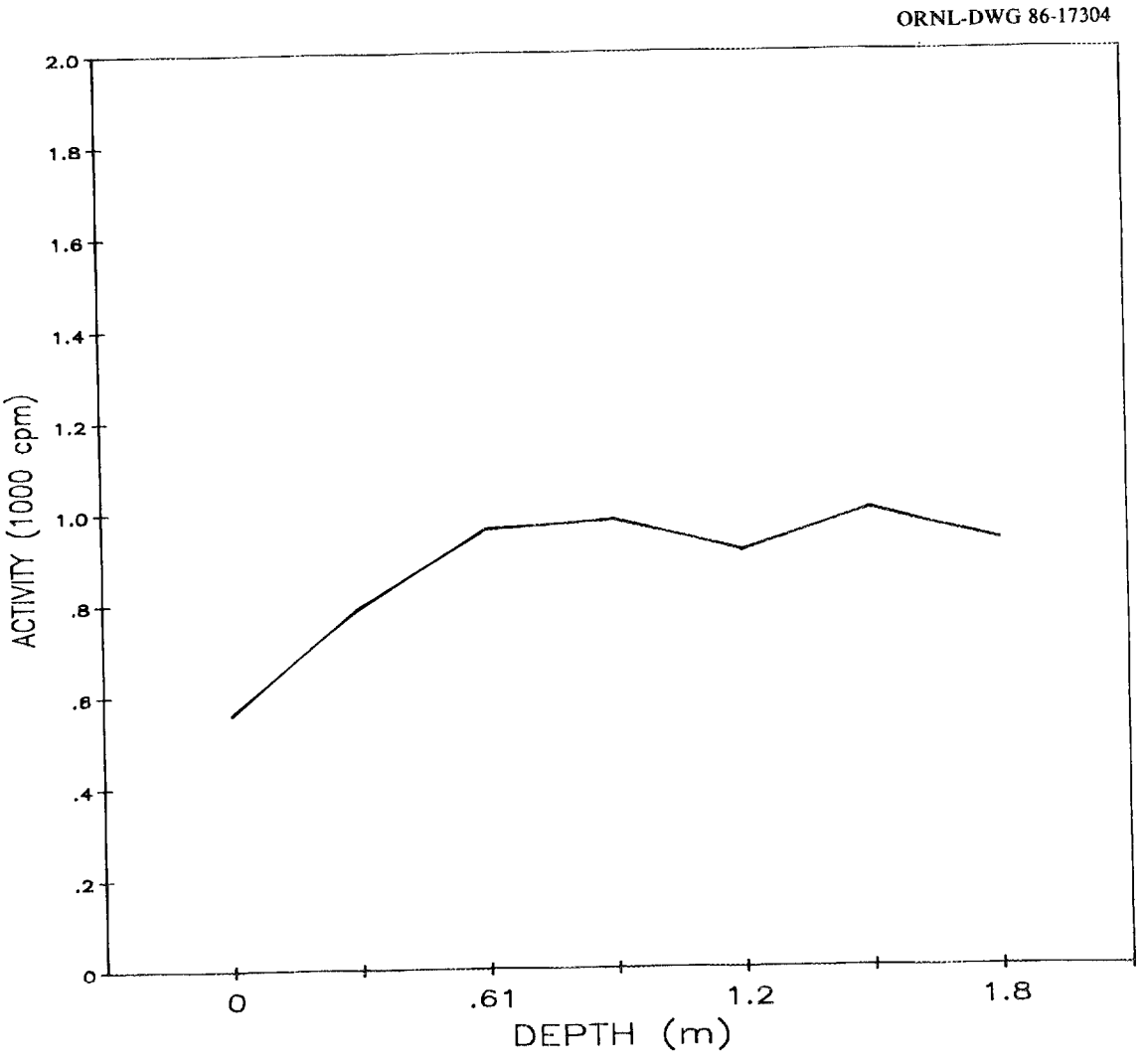

Fig. A.12. Gamma profile of auger hole 13.

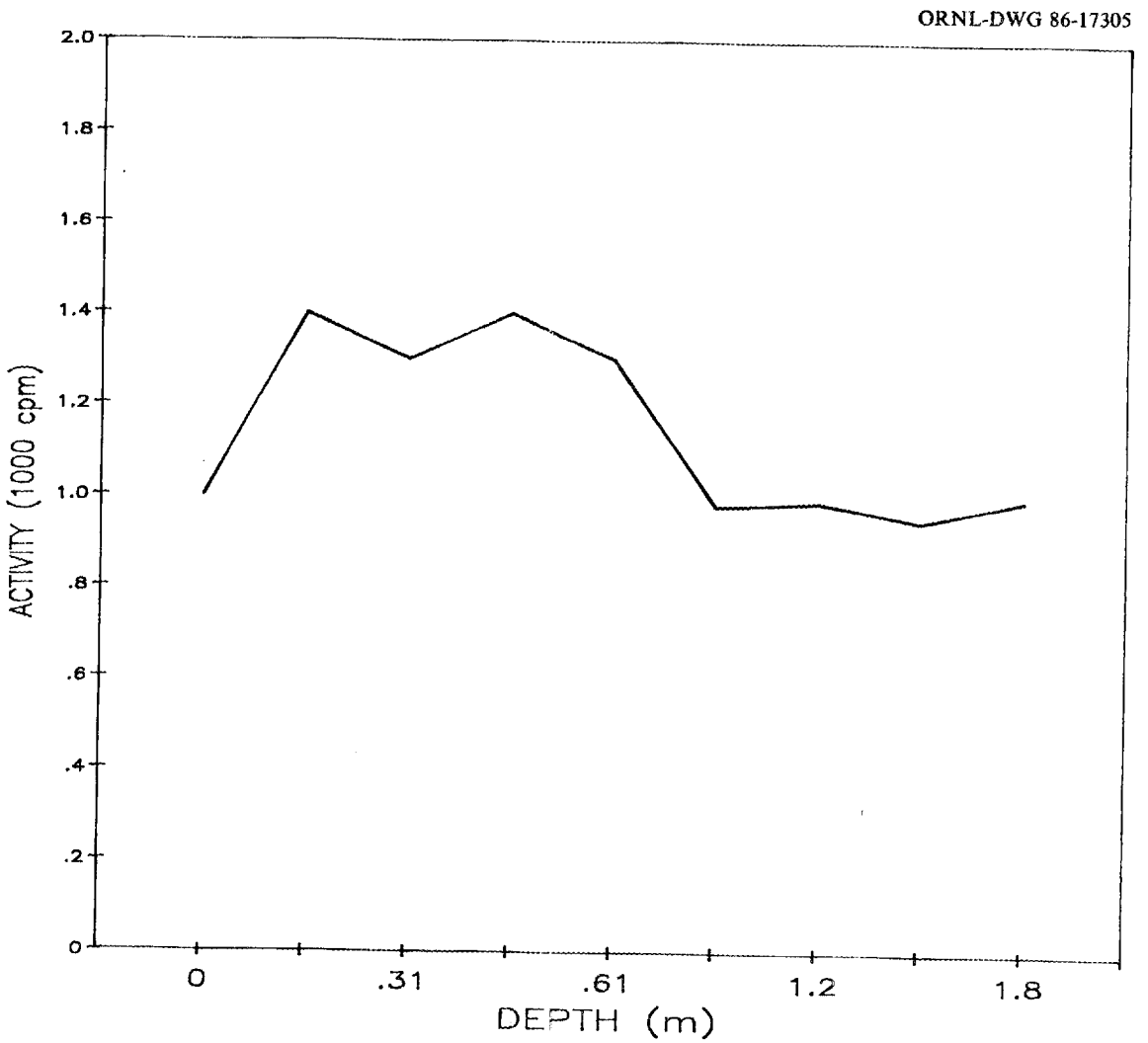

Fig. A.13. Gamma profile of auger hole 14.

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